Scanning Laser Radar Development for Solar System Exploration Applications

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ABSTRACT

The Jet Propulsion Laboratory (JPL) has recently established an accelerated development initiative to enable high-resolution active optical ranging and terrain mapping capabilities for a series of upcoming Solar System exploration missions. Building on existing NASA airborne terrain mapping and spaceborne laser altimetry technologies, the JPL program seeks to develop a family of instruments which will serve the increasingly demanding navigational requirements of future robotic sciencecraft. Amongst the most challenging of these will be the Mars Sample Return (MSR) mission. The current MSR mission concept calls for the sampling of Martian terrain by two lander vehicles, followed by storage of the cached samples in Mars orbit and their eventual retrieval and return to Earth by a separate spacecraft. The complex rendezvous strategy that has been evolved to accomplish this goal places stringent demands on the autonomous navigation capabilities of the carrier vehicle and high-resolution (~1 cm) acquisition and ranging lidar is a critical enabling component of the overall approach. In addition, risk mitigation provisions to be enacted under the re-architectured Mars Exploration Program will require increased assurance of safe landing conditions for future landed Mars missions. Consequently, we are also formulating designs for a terrain mapping lidar as part of an autonomous landing site selection system to be activated during the final stages of the entry/descent/landing operation on upcoming missions. These applications and others in solar system exploration will be described in this presentation.

1. Introduction

Over the next decade and beyond the US National Aeronautics and Space Administration (NASA) will evaluate numerous deep-space exploration mission concepts as possible candidates for expansion of the Solar System Exploration Program. The ambitious science goals of these proposed missions frequently contrasts with the resources available to bring them to fruition, driving the associated technical requirements levied on robotic spacecraft to challenging levels which demand increasingly innovative approaches to their technological implementation.

Amongst the current palette of missions under consideration are several that require on-board high precision ranging and navigation capability. The approach that is perceived to offer the greatest benefit in this regard is laser ranging. While laser ranging now has a significant space heritage in terrestrial (Abshire *et al.*, 1998; Bufton *et al.*, 1999), lunar (Kaula *et al.*, 1974; Smith *et al.*, 1997), and deep-space (Zuber *et al.*, 1997; Sakimoto *et al.*, 1999) applications, these are essentially "staring" instruments configured for full body altimetry of their respective targets with somewhat coarse horizontal resolution. For the navigational applications at issue here the requirement is for much greater areal density of measurements than has hitherto been contemplated, so that a radically different approach is required.

The NASA New Millennium Program Deep Space 4/Champollion mission (Muirhead and Kerridge, 1999) provided the original impetus for the ensuing development effort. Prior to its rescoping and eventual cancellation in the summer of 1999 due to budgetary constraints, DS-4 was to rendezvous with Comet Tempel I and, *inter alia*, perform a high-resolution topographic survey of the comet nucleus with a scanning laser ranging instrument. The resulting digital terrain elevation map of the cometary nucleus was then to have been used to select a suitable landing site for a surface sampling and Earth-return probe. Autonomous safe approach and landing of the probe would be aided by additional altimetry and terrain elevation information also provided by the laser altimeter aboard the lander module.

Although ultimately deselected, the DS-4 mission study resulted in a valuable body of knowledge from which the current program has benefited considerably.

2. Target Missions

At present, three currently baselined mission types anticipate some level of use for the high-resolution laser ranging apparatus described here. The short term applications are resident within the Mars Exploration Program, which at the time of writing is undergoing a major re-architecturing exercise to identify and mitigate sources of perceived risk.

a. *Mars Surface Landers*

The nature of the Martian surface (or indeed any planetary or small body surface) will always constitute a major source of risk to any spacecraft which attempts to land there due to the potential interference of terrain features with the lander support structure. In the case of the Mars Pathfinder mission of 1997 (Golombek *et al.*, 1999) this risk was successfully addressed using the novel approach of making landfall with the vehicle protected by airbags which were then deflated to expose the payload to the Martian elements. Future landed missions will carry heavier payloads which will be less amenable to this approach, so that some means for examining prospective landing sites during descent is desirable to enable the lander to autonomously navigate the final descent phase to a relatively hazard-free area.

The baseline profile for this scenario calls for activation of the laser radar at an altitude of ~3 km with continuous operation thereafter down to the 50-m altitude level at an approximate 1-Hz frame rate. During the terminal phase the required ranging accuracy is 10 cm over an approximately 40m x 40m search area.

b. Mars Sample Return

The proposed Mars Sample Return (MSR) mission presents an especially challenging prospect. Although currently under review, the original schedule anticipated the collection of two samples of Martian material by two separate landers, their insertion into Mars orbit contained in 16-cm diameter near-spherical transfer vessels (orbiting sample, or OS), and their eventual retrieval and return to Earth by a separate spacecraft.

The ship-to-ship rendezvous strategy in Mars orbit must assure the safety of all three discrete elements (*i.e.*, the two OSs as well as the return carrier craft), so that the possibility for recognition and subsequent abort of a potentially fatal missed approach has to be accommodated in the autonomous navigation software.

Following initial target acquisition with the aid of a solar-powered radiolocator beacon aboard the OS, operational hand-off to the scanning laser radar is desired at a closing range of 5 km with the rendezvous operation to be tracked until the closing distance has reached ~50 cm. Within the final 10 m of approach a ranging accuracy to the OS of 2.5 cm is desired.

c. Comet Nucleus Sample Return

The Comet Nucleus Sample Return (CNSR) mission is conceptually equivalent to the cancelled DS-4 mission referred to in the Introduction (Muirhead and Kerridge, 1999). While only in the exploratory phase at present, the estimated requirements for the approach/landing lidar are at this time expected to differ little from those originally envisaged for DS-4. Hence, a functional measurement range of 0.5 - 5000 m is presently baselined with ranging accuracy of 1 m at 5 km, grading to 2 cm within 100 m of the comet nucleus. A 10^4-pixel frame occupying a 10° x 10° field will have a 0.5-Hz update rate.

3. Technical Approach

The philosophy adopted in the JPL system studies strives to achieve the optimum possible degree of commonality between the individual application areas. Maximum use of space qualifiable COTS components is desirable.

The laser transmitter specification calls for 50-μJ, 3-ns pulsed operation at a PRF of 10 kHz and assumes neodymium laser technology (*i.e.*, wavelength ~1064 nm). A receiver aperture diameter of ~6 cm has been identified as representing an optimum trade between radiometric/ranging performance and the resource constraints imposed by spacecraft considerations. Consequently, the accommodation requirements currently being assumed for the rendezvous applications are: 4 kg mass, 25 W power dissipation, 2 dm^3 volume. The Mars lander instrument is estimated to require up to 15 kg and 100 W of power, reflecting the more aggressive scanning requirements that have to be met to achieve the landing hazard avoidance application.

JPL is currently initiating an engineering model development intended to identify and retire technology issues which must be addressed prior to deployment of the laser radar in space. The duration of this effort is expected to be 2 years.

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